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THESIS

A COMPARISON OF PEGASUS AND COMBINED
CTD/ADCP CURRENT PROFILES
OFF THE CALIFORNIA COAST

by

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Vertical profiles of alongshore and cross-shore velocities obtained by PEGASUS, a free-falling, acoustically tracked current profiler, and an Acoustic Doppler Current Profiler (ADCP) are compared. Data was collected during November, 1988 near Point Sur, California. Processing of data for both instruments is discussed in some detail.

Velocity profiles and contours show good correlation in feature location but often differed significantly in intensity. Alongshore velocity components from the two instruments were more highly correlated than were cross-shore components. Alongshore velocities also agreed well with both geostrophy and historical data.

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i

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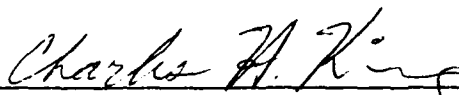requirements for the degree of
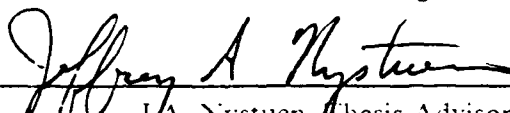
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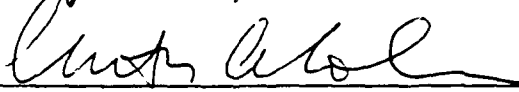OCEANOGRAPHY

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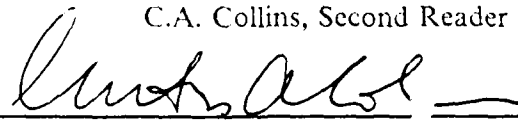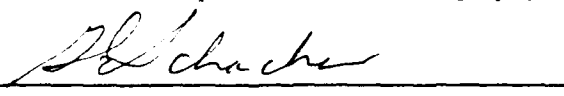
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ii

ABSTRACT

Vertical profiles of alongshore and cross-shore velocities obtained by PEGASUS, a free-falling, acoustically tracked current profiler, and an Acoustic Doppler Current Profiler (ADCP) are compared. Data was collected during November, 1988 near Point Sur, California. Processing of data for both instruments is discussed in some detail.

Velocity profiles and contours show good correlation in feature location but often differed significantly in intensity. Alongshore velocity components from the two instruments were more highly correlated than were cross-shore components. Alongshore velocities also agreed well with both geostrophy and historical data.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

I. INTRODUCTION

The long history of current measurement has included numerous methods, the two most common in recent years being Lagrangian drifters and moored current meters. However, these instruments have major drawbacks, especially where measurement of vertical profiles of velocity throughout the water column is concerned. Lagrangian drifters are unable to provide profiles, although they can give good definition of the path a particular parcel of water follows. Moored current meters are limited to measurements at a single point in the horizontal and vertical, and numerous instruments are required to give good vertical resolution. Even if a sufficient number of instruments is available to give good coverage, they are unsuitable for use near the surface due to their inability to respond to the short time scale variations present there. Also, the near surface regime is hard on instruments in general. The size of the anchor and release mechanism restrict the placement of moored current meters very near the bottom. Until fairly recently, high quality, high resolution vertical velocity profiles were nearly impossible to obtain. With the advent of PEGASUS, a free falling current profiler, and the Acoustic Doppler Current Profiler (ADCP), these profiles can finally be obtained.

Several papers have been written discussing theory, data processing, error analysis, etc., of these two instruments. Studies have been done comparing moored current meters to both PEGASUS and ADCP [Refs. 1, 2 , 3, 4, 5 ,6]. These particular studies generally compared data on a coarse vertical spacing due to the limitations of the moored current meters. Nothing is in the current literature concerning the intercomparison of profiles obtained using these two instruments.

This study is a comparison of data obtained using PEGASUS and ADCP during the California Undercurrent Cruise conducted by the Naval Postgraduate School aboard the *RV Point Sur* during the period 22-27 November, 1988, near Point Sur, California. Chapter 2 briefly discusses these two instruments. In some detail, Chapter 3 discusses the processing and analysis of data obtained by them. Chapter 4 intercompares the upper water column PEGASUS, ADCP and geostrophic velocity profiles. In addition, surface-to- bottom PEGASUS profiles will be compared to geostrophic profiles which have been referenced to an ADCP level-of-known-motion, and deviations from geostrophy will be discussed.

II. DATA COLLECTION AND INSTRUMENTATION

The data used in this study was collected during the 22-27 November, 1988 California Undercurrent Study cruise conducted by the Naval Postgraduate School. Data was collected along what is known as the Point Sur Transect, a series of oceanographic stations which are periodically reoccupied near Point Sur, California. The transect, shown in Figure 1, runs along 36°20'N until it intersects CalCOFI line 67, where the transect turns to the south-west to follow that line. This cruise occupied additional stations to the north-east of 36°20'N along CalCOFI line 67. For this study, only a portion of the transect was used, consisting of CTD stations eight through 18 and PEGASUS casts 53 through 63 with the exception of 56. ADCP data was also available for the same locations, at times corresponding to the PEGASUS casts. Other PEGASUS casts shown on Figure 1 were not used due to either bad PEGASUS data or missing ADCP data. In general, the PEGASUS data was bad either due to dropping PEGASUS too close to the line between the transponders or the transponders were too weak to give a ping strong enough to be detected by PEGASUS.

PEGASUS velocity data was available from the surface to the bottom. CTD data was collected from the surface to within 200 meters of the bottom. ADCP data was available to a maximum depth of approximately 500 meters, with the majority of good data being at 400 meters or shallower.

A. PEGASUS

PEGASUS is a free falling, acoustically tracked device capable of giving high resolution vertical current profiles. It consists of a free-falling sphere which emits a sonar pulse every 16 seconds. This sonar pulse is received by two bottom mounted transponders, whose depths and locations relative to each other have been previously surveyed, and a response pulse is emitted. PEGASUS receives this response and stores, in an internal memory, the round trip travel time of the pulse, along with temperature and depth. This process repeats during both the downcast and the upcast, giving two vertical profiles at roughly the same point in the ocean but slightly separated in time. The instrument is retrieved and the stored data is copied for later processing. More thorough discussions of this instrument are given by Spain, et al. [Ref. 7] and by Cole and Dorson [Ref. 8].
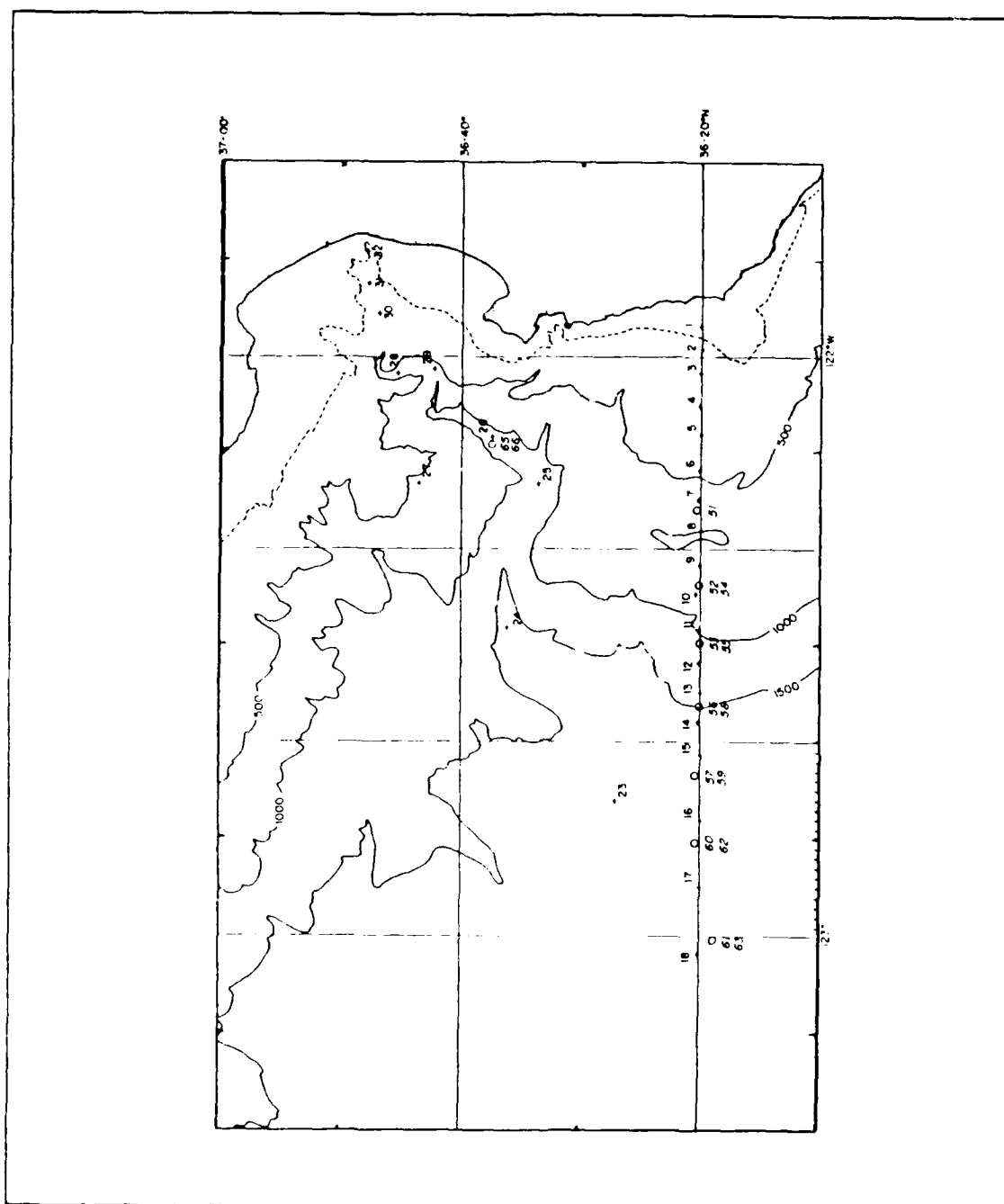
Figure 1. **Data Collection Stations:** This study uses PEGASUS cast stations, 53, 54, 55, 57, 58, 59, 60, 61, 62 and 63, indicated by circles (○). The +'s indicate a CTD stations. Depths are in fathoms.

PEGASUS vertical resolution, during the downcast, is a function of it's fall rate, which is nominally 38 meters per minute. This gives a position at approximately 10 meter intervals. This is similar to the resolution during the upcast, which is dependent upon the buoyancy of the instrument. Fall rate can easily be adjusted to give very high resolution, but decreased fall rate increases the time between launch and recovery drastically. For a 3500 meter cast, halving the fall rate, from 38 meters per minute to 19 meters per minute, would increase the time between deployment and recovery from 3 hours to 4.5 hours.

The horizontal resolution of PEGASUS is very small. PEGASUS is similar to a rawinsonde in that it must physically pass through a feature to detect it. In the case of features with small horizontal scale, PEGASUS can give the false indication that the feature is either very strong or non-existent. Fortunately the ocean is generally horizontally stratified and this problem is minimal.

The PEGASUS instrument used in this study used two transponders operating at 12 kHz and 12.5 kHz and oriented roughly on a North-South line. The separation between transponders was roughly equal to the water depth. For the stations where two casts were done, the casts were spaced approximately one-half inertial period apart. Table 1 on page 5 gives the times of the various PEGASUS casts.

B. ADCP

The Acoustic Doppler Current Profiler (ADCP) is a multi-beam sonar with it's beams oriented typically 30° from the vertical which measures the doppler shift of the return signal in each beam as a function of depth. The doppler shift is caused by movement of scatterers in the water column relative to the transducer head. On a stationary platform, the doppler shifts in several beams can be combined directly to provide absolute velocity profiles. However, on a ship, navigation data must be included to give absolute velocity [Ref. 9]. In addition, ADCP velocities are inherently noisy and numerous profiles, on the order of hundreds, must be averaged together in order to provide good vertical shear information. Even more profiles must be included in the average to provide good absolute velocities. Kosro [Ref. 3] states that while 5 minutes of data (about 475 pings) is sufficient for vertical shear determination, 30 minutes of data (2900 pings) is required for determination of absolute velocity.

The major sources of error include the accuracy of ADCP coordinate alignment with ship coordinates, misalignment of which results in the rotation of forward ship velocity into an apparent cross-track velocity, and poor ship navigation information, resulting in

4

Table 1.   TIMES OF PEGASUS CASTS

PEGASUS cast #	Date/Time	Water Depth (m)
53	9/23 16:04	1850
54	9/23 20:19	1200
55	9/24 01:36	1850
57	9/24 18:48	3175
58	9/24 22:53	2550
59	9/25 06:21	3175
60	9/25 10:15	3200
61	9/25 14:20	3475
62	9/25 21:07	3200
63	9/26 01:21	3475

noisy and generally poor absolute velocity profiles. An excellent discussion of ADCP theory of operation. data processing and error analysis is given by Kosro [Ref. 3].

The horizontal resolution of the ADCP decreases as a function of depth due to the horizontal spreading of the beams with depth. This can result in an underestimate of the intensity of features which are, especially, small and deep as they will be averaged out when the data from the beams are combined.

The profiler used in. this study was an RD Instruments RD-DR0300 operating at 307.2 kHz with four beams in a JANUS configuration.[Ref. 10] Doppler shift data was averaged for three minutes (about 200 pings), the result being stored on diskette along with time and ship position, speed, and heading. The vertical resolution of the stored data is 4 meters.

C.   CTD

The CTD sensor used here was a Neil Brown Mk IIIB CTD. Data was collected to within 200 m   of the bottom, during the downcast only, as one meter averages. Table 2 on page   es the times of the various CTD casts.

Table 2. TIMES OF CTD CASTS

CTD cast #	Date/Time
8	9/23 06:19
9	9/23 06:58
10	9/23 11:54
11	9/23 13:18
12	9/23 18:16
13	9/23 22:48
14	9/24 13:42
15	9/24 15:53
16	9/25 02:46
17	9/25 18:55
18	9/25 15:00

III. DATA PROCESSING

A. PEGASUS

The processing of data collected by PEGASUS to give a vertical profile of horizontal velocity is a three-dimensional navigation problem. The raw data consist of distances from two, or possibly three, bottom mounted sonar transponders, in the form of two-way travel times, and the distance from the surface, in the form of pressure. The orientation of the transponders relative to each other is known accurately based on previously conducted surveys. From the three distances recorded, it is possible to calculate the horizontal position of PEGASUS as a function of depth. Once these positions are known, simple finite differencing results in a profile of horizontal velocity.

PEGASUS records pressure, temperature, and two-way travel times on both the downcast and upcast, providing two profiles of horizontal velocity through the entire water column at basically the same location but at slightly separated times. The downcast and upcast rates are nominally the same, about 38 meters per minute. This results in, based on the rate of one ping every 16 seconds, a position every 10 meters vertically. In one case in this study (Cast 55), the downcast rate was approximately 19 meters per minute while the upcast rate remained at 38 meters per minute. In addition, this cast has a separation of almost eight hours between the start of the downcast and the end of the upcast, because of the slower fall rate due to loss of some weight and fouling of the weight release mechanism during deployment.

Initial data processing, which involved conversion of raw travel times into positions and subsequently to velocities, was done on a personal computer using routines written in Turbo-Basic by Tarry Rago of the Oceanography Department of the Naval Post-graduate School. The routines were based on the PEGKEY programs of Lillibridge and Rossby [Ref. 11]. These programs allow the option of filtering the data during initial velocity calculation. Lillibridge and Rossby [Ref. 11] recommend using a filter halfwidth of three depth increments, equivalent to 30 meters in this study, chosen based primarily upon studies in the Gulf Stream. However, it was found in this study that, when the filter was used with a halfwidth of greater than one, small scale features were often totally removed from the resulting velocity profiles when the features were believed to be real due to excellent correlation with features in corresponding ADCP profiles. This prompted the use of a halfwidth of one in initial velocity calculation, resulting in a sim-

ple leapfrog finite difference velocity calculation. This allowed much greater control of the filtering, which was done later in the processing. The resulting velocities were defined with U being positive eastward and V being positive northward.

Some noise exists in the velocities calculated, probably due to bad travel time data. It is impossible to correct, except for the use of simple interpolation, for any bad travel times in the case where two transponders are used. In the case of three transponders, bad data can be spotted and corrected fairly easily due to the overdetermined system. The velocity data was filtered vertically using a Hanning window filter. The variance in the profiles as a function of window halfwidth showed a steady but only very slight decrease in variance with increasing filter width. Based primarily on visual inspection of filtered versus unfiltered profiles, it was decided that a filter halfwidth of 30 meters would be used for most of the data sets. PEGASUS cast 55, which had a higher resolution on the downcast than other casts, was filtered using a 15 meter halfwidth. This used the same number of data points in the filter as was used on the other data sets. Figure 2 shows an example of an unfiltered profile and the same profile after the filter has been applied. Finally, the PEGASUS profiles were separated into separate upcasts and downcasts and linearly interpolated to the same depths as ADCP profiles for data comparisons.

B. ACOUSTIC DOPPLER CURRENT PROFILER

Briefly stated, the processing of ADCP data consists of converting doppler shift records, recorded as a function of depth, to a vertical profile of absolute velocity. In theory, this is a very straightforward and simple operation. In practice, numerous complications are introduced into the processing.

Initial processing entails converting doppler shifts to horizontal and vertical velocity components, relative to the ADCP transducer head, as a function of depth, or as it is more commonly referred to, bin number, each bin being 4 meters deep. The method used here is identical to that described by Kosro [Ref. 3]. The doppler shifts are recorded as averages of three minutes of data so relative velocity profiles are calculated at three minute intervals. The velocities here, and throughout all subsequent processing, are calculated as U, V and W components, U being positive eastward, V being positive northward, and W being positive upwards.

Profiles of relative velocity must be corrected for a number of factors, the first of these being ship motion. Since velocities are initially calculated relative to the ADCP transducer head and the goal is to obtain absolute velocities, the effects of moving the

8
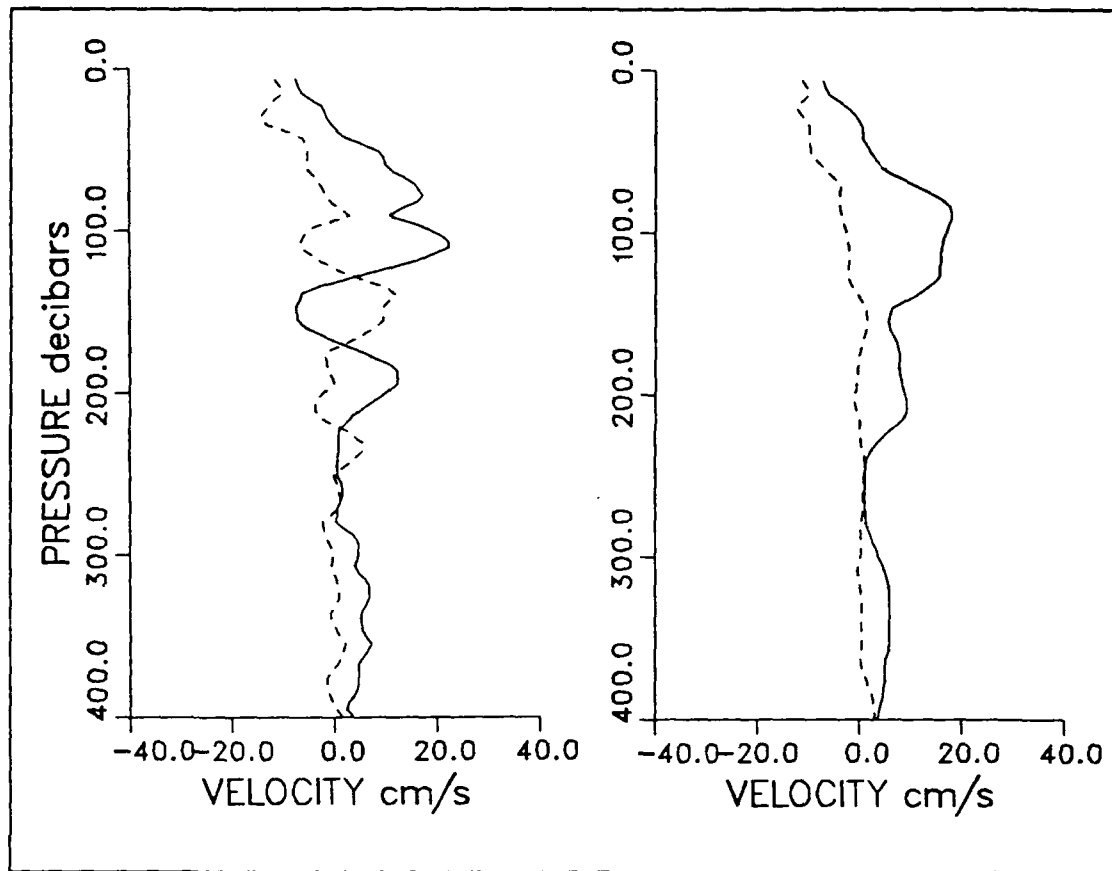
Figure 2. **Typical PEGASUS profile:** PEGASUS cast 57, downcast. The figure on the left is the unfiltered profile. The figure on the right is the same profile after being filtered with a Hanning window filter with halfwidth of 30 meters. The solid lines are U velocities, the dashed lines are V.

transducer head through the water must be removed. High quality ship navigation information is stored with each doppler shift record and can be used to compute ship motion.

Correction of the relative velocity profiles is not as straight forward as simply adding the U and V components of ship velocity to the U and V components of relative velocity. Since the relative velocities are very noisy, it has been found that a velocity correction calculated as the difference between ship velocity and the average velocities of several ADCP bins (reference layer) gives the best results. This is not immediately apparent in the resulting profiles but becomes so later in the processing, where profiles are time av-

eraged. It is found that correction of relative velocity profiles based on a single bin necessitates longer time averages, due to the noise in the ADCP profiles. The average velocity over several bins is far more representative of the actual velocity than any one bin by itself. It was found that the choice of the bins in the reference layer is relatively unimportant as long as the reference layer contains bins which are not at the very top or bottom of the profile and where at least 50% of the doppler shift data stored in the 3 minute average is good. The reference layer used in this study was made up of bins 15 through 19 (63 to 79 meters below the surface).

Normally, ship velocity is filtered in time prior to calculating absolute velocities [Ref. 3]. If the ship is continuously steaming, this filtering removes noise in the navigation data, resulting in smoother, and presumably better, ship speeds. However, filtering can introduce undesirable effects where large changes in ship speed or direction are encountered, these effects increasing as the averaging time of the raw ADCP doppler shift data increases. It should be noted that the ship speed recorded with the doppler shift data is an instantaneous ship speed and the use of ship navigation information results in a better average ship speed.

Consider the case where a ship is initially steaming but is coming on-station. A doppler shift record taken while the ship is steaming will contain only data while the ship is moving, and absolute velocities should be computed based on the ship motion while the ship is steaming. Likewise, a doppler shift record taken while the ship is on-station will contain only data obtained while the ship is on-station, and absolute velocities should be computed based on the ship motion while the ship is on station. Filtering of the ship velocity introduces erroneously large ship velocity into the early on-station time and erroneously small ship velocity into the late steaming time as the filter attempts to smooth out any large changes in ship velocity, resulting in very poor absolute velocities during that period of time. Similar results are obtained when considering change from on-station to steaming or large course changes. The effects increase as averaging time of the raw doppler shift data increases, since the data stored during the changes in speed and direction is not representative of either the period before or after the change.

Since the purpose of this study is to compare velocity profiles obtained using ADCP to those using PEGASUS, and the ship is typically on-station during a PEGASUS cast, ship velocities were not filtered in order to avoid the problems discussed above. The ship velocities were relatively noise free during the on- station periods. The data set was then edited to remove ADCP profiles obtained during periods while the ship was steaming.

The relative velocity profiles were converted to absolute velocity profiles by adding the reference velocity, computed as described above, to the entire relative velocity profile. The resulting set of profiles was edited to remove profiles while the ship was steaming as well as profiles which were extremely questionable. This editing procedure was very subjective and extreme care had to be taken to avoid alteration of the data set to an extent which would significantly affect the subsequent processing of the data. An objective procedure, possibly using correlation coefficients between subsequent profiles, would be helpful in avoiding the possible problems associated with subjective editing.

The resulting data was combined, so that a separate ADCP data set was obtained for each of the ten PEGASUS profiles used in the study, and edited, to remove the profiles recorded before the ship came on station, after the ship left station, and those with erroneously large absolute velocities, a sign that the ship velocity used for absolute velocity calculation was in error. The majority of the profiles removed occurred near the time the ship was coming to or leaving station. The processing of data to this point was done on a personal computer using programs written in Turbo-C by Paul Jessen of the Oceanography Department of the Naval Postgraduate School. Further processing was done on the IBM mainframe at NPS using routines written in Fortran.

Due to the noisy nature of the ADCP profiles, it was necessary to apply a vertical filter. A Hanning window filter was chosen for this purpose. In order to determine the optimum filter length necessary to reduce the noise, a variance analysis was undertaken. The mean velocity for computing the variances was calculated using bins 10 through 30 (43 to 123 meters). In order to compare the variances of the various profiles in a data set, a limit had to be set on the deepest point which should be included in the variance calculation. This was chosen to be the bottom depth of the shallowest profile in the data set. In this way, variances were calculated over the same depth for each profile in the data set. In addition, variances were normalized to the unfiltered variance to allow comparison of the various data sets.

The results of the variance analysis (Figure 3) showed that the optimum filter halfwidth was two to five bins (eight to 20 meters), depending upon the data set. Due to the fact that the ADCP data was to be compared to PEGASUS data and should therefore be filtered over a similar depth range, a filter halfwidth of seven bins (28 meters) was ultimately used in order to match, as closely as possible, the 30 meter halfwidth used for the PEGASUS profiles. Similar variance reduction was realized for this filter as for halfwidth's of two to five. The ADCP data set which corresponds to PEGASUS cast 55, was filtered using a 4 bin (16 meter) halfwidth filter in order to match the filter

11

width used on that PEGASUS data set. Examples of unfiltered and filtered ADCP profiles are shown in Figure 4. Note that there are large differences in the absolute velocities while the shears are very similar.

After vertically filtering the ADCP data, time averages were still necessary to provide reasonable absolute velocity profiles. It was desired to average the data over a time sufficient to provide good shear and absolute velocity profiles without averaging out actual changes in the ocean. Analysis showed that averaging 15 minutes of data provided a substantial reduction in both variance and the second moment about the origin with no significant reduction for longer time averages (Figure 5). The second moment about the origin is identical to the variance except that a mean value of zero is used. The 15 minute averages provide good absolute velocities.

The reduction in variance shows that additional noise not removed by the vertical filter is being removed from the profiles, while the reduction in the second moment about the origin shows that the absolute velocities are becoming more similar between the profiles. (Note that the variances and first moments are the averages of the normalized values for four different data sets.) The 15 minute averaging interval compares favorably with those of Refs. 3, 4 , 5, 9, and 12. Based on this analysis, 15 minute averages were used for further data analysis. Examples of these 15 minute averaged profiles will be presented later.

At this point, a few questions which arose during data processing should be addressed. The first concerns the time interval at which ADCP doppler shift averages should be recorded. The present study records 3 minute averaged data while other studies record data based on anything from individual pings [Ref. 3] to five minutes of data (currently used for certain cruises at NPS). Each of these has it's advantages. Recording data from individual pings results in a data set which can be manipulated very well to remove the data during, for example, large changes in ship speed or direction while losing a minimum of data. It has the major drawback of providing massive amounts of data, on the order of one ping per second or almost 200 times as much raw data as was used in this study. The recording of averaged data has the advantage of providing smaller data files which are easier to manipulate. It has the drawback of increased data loss during course and speed changes, since all data during the course or speed change should, ideally, be removed. It is felt that three to five minute averages are adequate, since time averaging is applied later in the processing anyway and no large changes are expected to occur in the ocean on time scales shorter than that. This allows

12
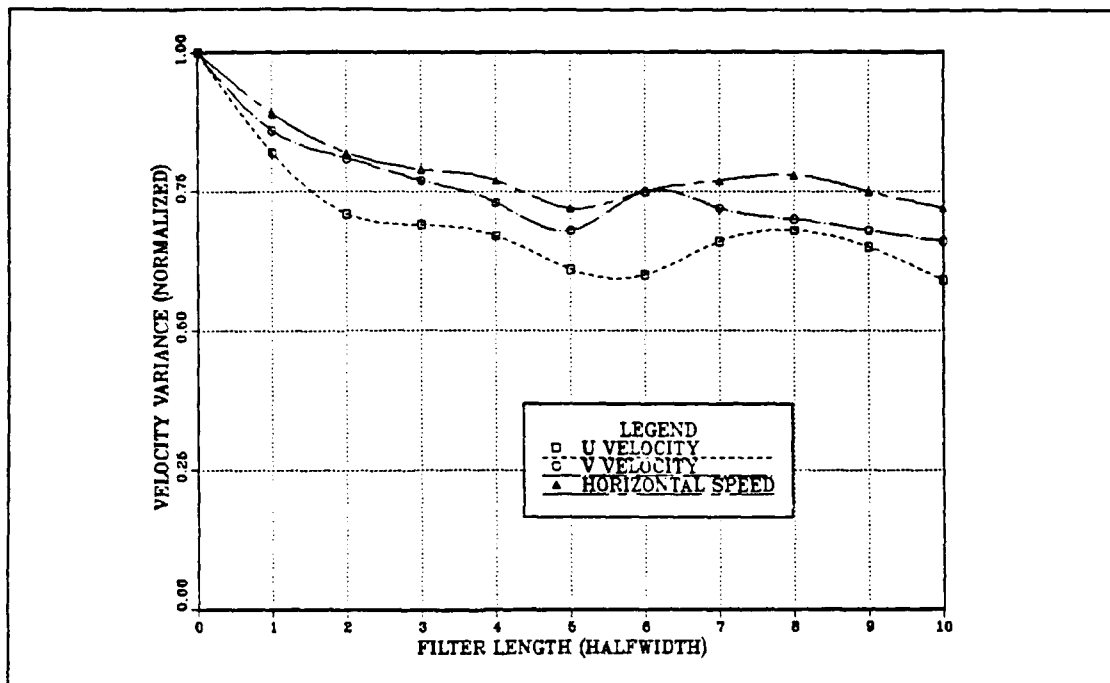
Figure 3. Variance of velocity as a function of filter length: ADCP data. Variance has been normalized to the unfiltered variance. This plot is the average of data for 4 different data sets.

data sets which are small enough to be manageable while minimizing data loss during editing.

A second question, which hinges on the above discussion, is whether the data can be edited in such a way as to keep data during both steaming and on-station periods. It is felt that this can be done if the data is *1)* split into two data sets; one while on station and another while steaming and *2)* judiciously edited, preferably using an objective editing routine, to remove the data during course and speed changes as previously discussed. It may then be possible to recombine them after the calculation of the absolute velocities is complete. However, this is speculation and has not been tested.

A third question arose concerning the errors which ship's heading and misalignment of the ADCP transducer to ship coordinates would introduce through rotation of ship forward velocity into an apparent cross-track velocity, as discussed by Kosro [Ref. 3] and Didden [Ref. 13]. Since this data has been edited to include only the period while the ship was on-station, forward motion is very small, as is the apparent cross-track velocity

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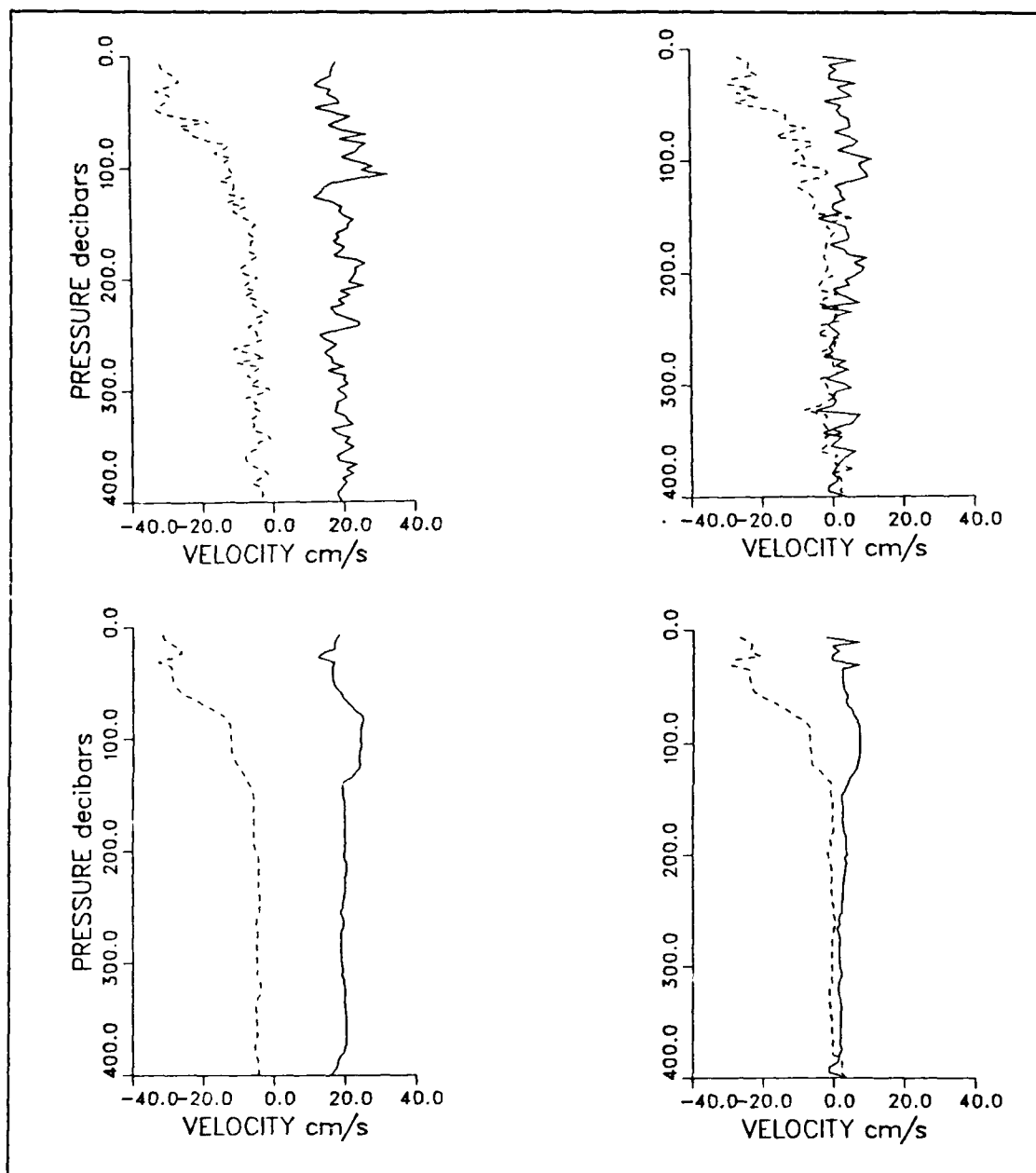
Figure 4. **Typical ADCP profile:** Profiles correspond to PEGASUS cast 57. Profiles are three minute average profiles. Profiles on right are 3 minutes later than profiles on left. Upper profiles are unfiltered. Lower profiles have been filtered using a Hanning window filter with halfwidth of 30 meters. U velocities are solid, V are dashed.

14
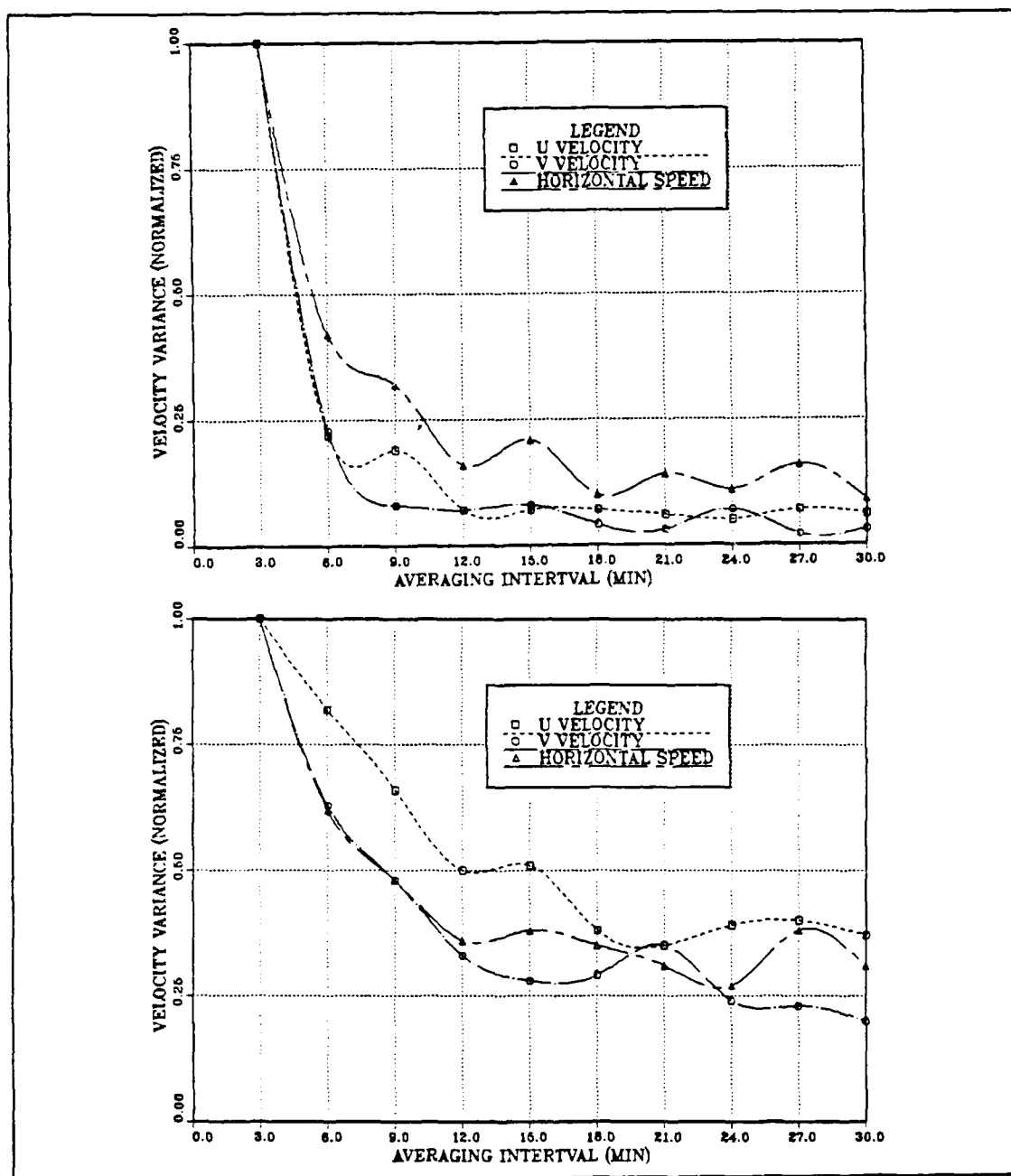
Figure 5. Variance reduction as a function of length of time average: ADCP data. The upper plot is the second moment about the origin, the lower one is the variance.

15

induced by misalignment. Only very small deviations from actual velocities would be expected and these were ignored. Without doubt, inclusion of steaming periods into the data set would necessitate far more accurate alignment than that which was done in this study. Alternatively, other methods for correcting for misalignment, such as described by Kosro [Ref. 3], could be used.

C. GEOSTROPHIC VELOCITY

Prior to geostrophic velocity calculation, the CTD data was quality control checked to remove data dropouts. The data was calibrated using bottle samples taken during the casts and checked for quality against data from previous cruises in the same locations.

Geostrophic velocities were calculated at two meter increments using an assumed level-of-no-motion (LNM) of 200 meters. The actual LNM is unimportant in comparing shear between two levels in the ocean, and since the geostrophic velocities were to be referenced to a level-of-known-motion (LKM) derived from the ADCP profiles, 200 meters was chosen arbitrarily.

Even though the resulting profiles were, as expected, very smooth, a vertical Hanning window filter was applied with a halfwidth of 30 meters in order to match the PEGASUS and ADCP data. Profiles were then horizontally interpolated to the PEGASUS cast points and linearly interpolated to the same depths.

The orientation of the line of CTD stations is such that the geostrophic velocities calculated are V velocities with V being defined as positive northward. This corresponds to the V velocities for both PEGASUS and ADCP.

IV. DISCUSSION

A. PROFILE COMPARISONS

1. Component Velocity Plots

ADCP and PEGASUS U and V component velocities were plotted together to visually evaluate the effectiveness of vertical filtering and time averaging. Variance analysis was used to find optimum vertical filter lengths and time averages, but visual component velocity profile comparisons aided these choices as well. These visual comparisons will be discussed in general with reference to specific casts or profiles where features of particular interest were noted.

It should be noted that, due to the method used for filtering the profiles, the top and bottom portions of the profiles should be compared cautiously. The large variation in these areas is an artifact of the filter. In addition, the PEGASUS downcast profiles often show erroneously large velocities near the surface due to the finite time required for PEGASUS to become adequately coupled with the currents.

The best visual correlations should be between the PEGASUS downcast and the ADCP profiles collected soon after the ship arrived on station; i.e. when PEGASUS was deployed. As the time separation between the PEGASUS downcast and the ADCP profile increases, correlation should be expected to decrease as the ocean begins to change and spatial variations, due to movement of the ship from the initial area due to drift, become important. This was the case for most of the profiles. A corresponding increase in visual correlation between the PEGASUS upcast and the ADCP profiles taken at the same times, which would also be expected, was seen in very few cases and was the exception rather than the rule. Figure 6 and Figure 7 show profile time series of a typical PEGASUS downcast and upcast, respectively, plotted with ADCP profiles 30 minutes apart to illustrate this. This also illustrates the internal consistency of the shear in the ADCP profiles. The V velocities show much greater internal consistency in the absolute velocities than do the U velocities. Note that there is less internal consistency in the ADCP profiles associated with the upcast than for those associated with the downcast due to the maneuvering of the ship in preparation for recovery of the PEGASUS. Also, note that there is much more decrease in the correlation of the U component than in the V component.

17

Figure 6. Time series of ADCP and PEGASUS (downcast) profiles: PEGASUS downcast 63. ADCP profiles are 30 minutes apart. PEGASUS velocity is the heavy solid line. Upper plot is U component, lower is V component. The circles are the ADCP profile corresponding closest in time the PEGASUS cast, triangles are later by 30 minutes, pluses by 60 minutes, and crosses by 90 minutes.
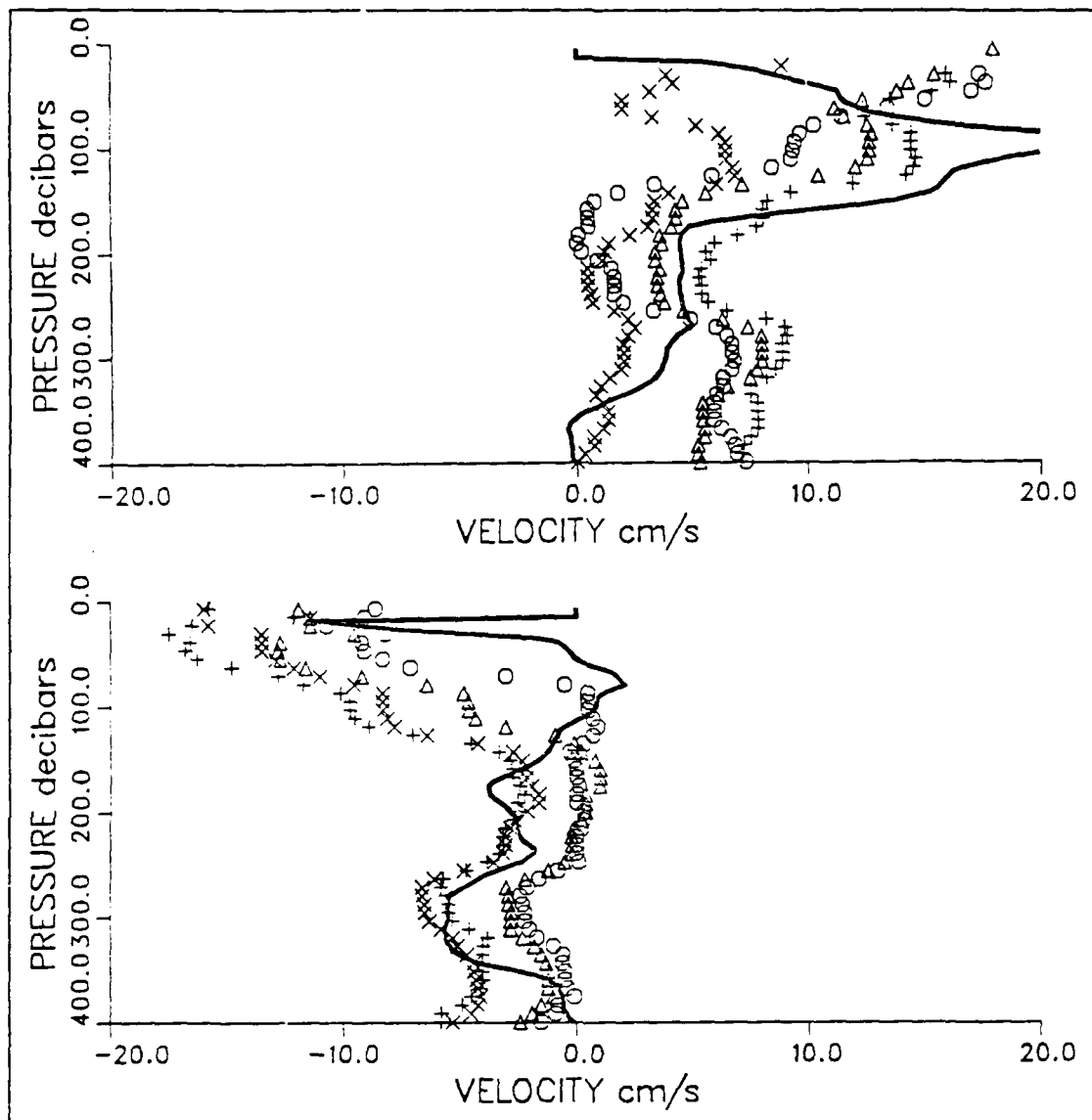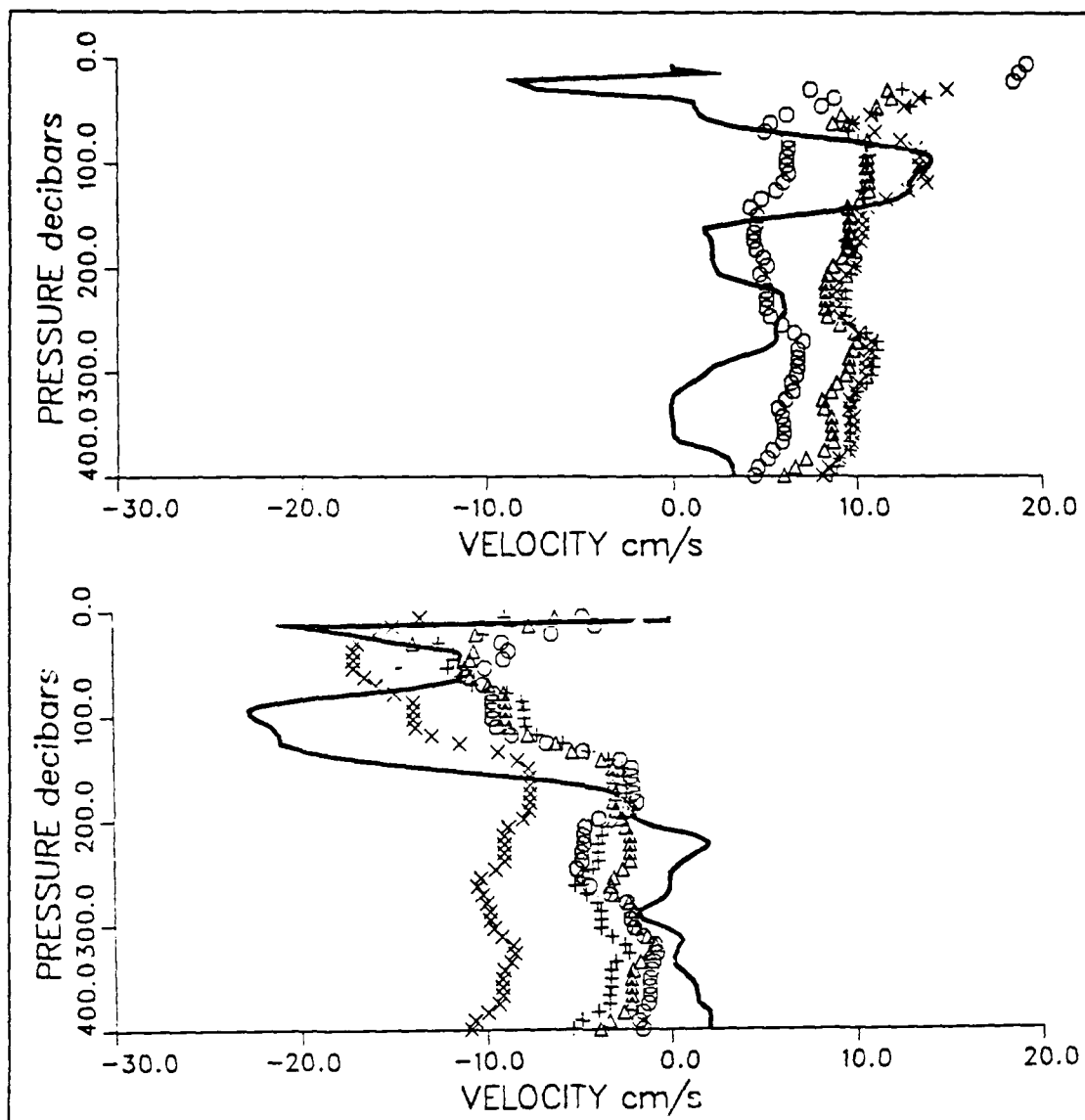
Figure 7.   Time series of ADCP and PEGASUS (upcast) profiles: PEGASUS up-
cast 63.   ADCP profiles are 30 minutes apart.   PEGASUS velocity is the
heavy solid line.   Upper plot is U component, lower is V component.
The circles are the ADCP profile closest in time to the PEGASUS cast,
triangles are earlier by 30 minutes, pluses by 60 minutes, and crosses by
90 minutes.

Generally, regions of large shear are qualitatively reflected in both the ADCP and PEGASUS profiles. In quite a few cases, the magnitudes of the currents agreed well but in some there were large differences. It was at first thought that these differences could be due to the use of 15 minute averages vice longer averages. Kosro's [Ref. 3] statement that five minute averages are sufficient for shear determination but 30 minutes were necessary for good absolute velocities would support this. However, 30 minute averages, when calculated and plotted, showed no noticeable improvement. Also, successive ADCP profiles showed velocities of the same magnitude, indicating that averaging was not the cause. The reason for the absence of further decrease in the variance and second moment about the origin seems to be that the ocean is changing on time scales of less than 30 minutes. This could be due to a number of factors including changes in wind forcing, propagation of internal waves, etc.

The U velocities consistently had poorer visual correlation of features than did the V velocities, presumably due to the consistently weaker U velocities. Horizontal speed $((U^2 + V^2)^{1/2})$ showed correlations similar to the V correlations in most cases, again due to the dominance of the V component.

The profiles normally showed large differences in the upper 50 meters or so of the water column. This can be attributed to several factors. The ADCP can experience degraded performance near the surface due to reverberation and reflection from near surface bubbles, etc. PEGASUS can provide erroneous velocities near the surface on the downcast if the ship velocity does not match that of the surface currents when PEGASUS is released, since that velocity will be transferred to PEGASUS upon deployment, requiring a finite time to come to equilibrium with the water velocity. Also, direct and surface reflected transponder signals can interfere due to their similar path length, and it is possible that PEGASUS may record the surface reflected travel time, resulting in bad position data. The filter applied helps to remove some of these problems but caution must still be exercised when evaluating near surface currents.

The profiles also showed larger differences, in general, deeper in the profile than at mid-depths. The ADCP profiles did not show features such as areas of high shear there as well as did the PEGASUS profiles, especially when the features had a small depth extent or were of small magnitude. Due to the ADCP's decrease of horizontal resolution with depth, it has the tendency to remove small scale features at deeper depths. If only one of the ADCP's four beams detects the feature, that feature will not show up strongly. The feature will be detected by PEGASUS if it passes through the

feature, no matter how small the feature is, and the strength of the feature in the profile will be more representative of the actual feature.

Many of the profiles showed a vertical offset of features, those on the PEGASUS profiles generally being deeper than corresponding ADCP features. It is possible that this offset is due to a simple offset in the PEGASUS pressure measurement but the offset is not consistent in either presence or magnitude. It is also possible that an error in the speed of sound used by the ADCP could offset the depths at which data is acquired, but this offset would change with depth, which is not apparent in the data. The speed of sound for ADCP purposes is calculated using an internally measured water temperature which has been previously noted, for Ametek-Straza instruments, to have a time delay [Refs. 12, 3]. Whether the RDI instrument used here has a similar problem is uncertain, but due to the fact that the ship is on-station, rapid temperature changes should not commonly occur and the problem should be minimal. The offset is not always the same on the upcast as the downcast, the difference possibly being due to a hysteresis problem in the PEGASUS pressure sensor [Ref. 7]. The hysteresis problem has reportedly been corrected. More likely the problem is due to internal waves. Even though the offset can be easily corrected for by shifting the profiles up or down slightly to match feature depths, the reason for the offset needs to be understood more fully.

Profiles taken at shallow stations tended to show much higher visual correlation than those in deeper water. No apparent reason for this has been found except for the possibility that PEGASUS may record the surface reflected travel time when in deeper water because of the weaker signal due to the large distance to the transponders. However, this is speculation and needs to be tested. It is certain that some of the deep water transponders are running low on battery power, lowering their source level, thus further complicating the matter.

Ideally, plots of PEGASUS velocity versus ADCP velocity, taken at the same time and place, would have a slope of one and an intercept of zero. The plots should increasingly deviate from this ideal as the time separation between the profiles increases. This was generally found, with the best agreement with the ideal case being in U and V component velocities in the mid-depths. Also, U velocities showed higher adherence to ideality than did the V velocities due to the small U velocities typical of the area. Plots for PEGASUS cast 57 are shown in Figure 8. Cast 57 was fairly typical. Some casts deviated from ideality quite drastically. The worst agreements with the ideal were found in deeper water, but not all deep water cases were bad. Again, this could be due to weak

21

signals at the deep water stations. Poor agreement between the near surface ADCP and PEGASUS velocities were also seen.

2. Correlation Coefficients

(1) General Discussion . In order to quantify the qualitative information derived from visual profile comparison, correlation coefficients were calculated for many combinations of profiles. Coefficients for U and V velocity components and horizontal speed were calculated for each 15 minute average ADCP profile and the corresponding PEGASUS upcast and downcast, as well as for the PEGASUS upcast versus downcast. In addition, the PEGASUS upcast and downcast were shifted vertically by up to 44 meters in 4 meter increments and all correlations were recalculated to evaluate the change in correlation when the offset problem was "corrected".

All correlation coefficients were calculated without using data from shallower than 47 meters in order to avoid the high variability within the profiles near the surface. Also, the deepest data used varied from cast to cast. The deepest data was 28 meters shallower than the bottom of the shallowest ADCP profile for that cast. This was done to ensure that similar depth ranges were included in each correlation coefficient calculation and to avoid the portion of the data at the very bottom of the profile which is not filtered.

It would be expected that correlation coefficients between the PEGASUS downcast and upcast would be higher for shallow water cases since the time separation, which is normally directly related to water depth, is smaller there. It would further be expected that upcasts and downcasts which were separated by times approaching one-half of the inertial period would show lower correlation coefficients, with the U component in particular showing a larger decrease in correlation due to it's smaller magnitude and presumably larger inertial component. The U (cross-shore) component is expected to have a smaller magnitude, in general, than the V (alongshore) component, and this is supported by the observations. It was generally found that the shallow water cases did have higher correlation coefficients than the deep water cases. In fact, deep water cases quite often showed large negative correlations between the upcast and downcast, as large as -0.8 or greater. However, as will be discussed shortly, not all of these large negative correlations are thought to be correct.

Some complications enter when considering the effect of inertial oscillations on U and V component velocity correlation coefficients. This concerns the position within the inertial oscillation at which the velocities are measured. Note that the following discussion applies only for velocities with no mean flow component (purely
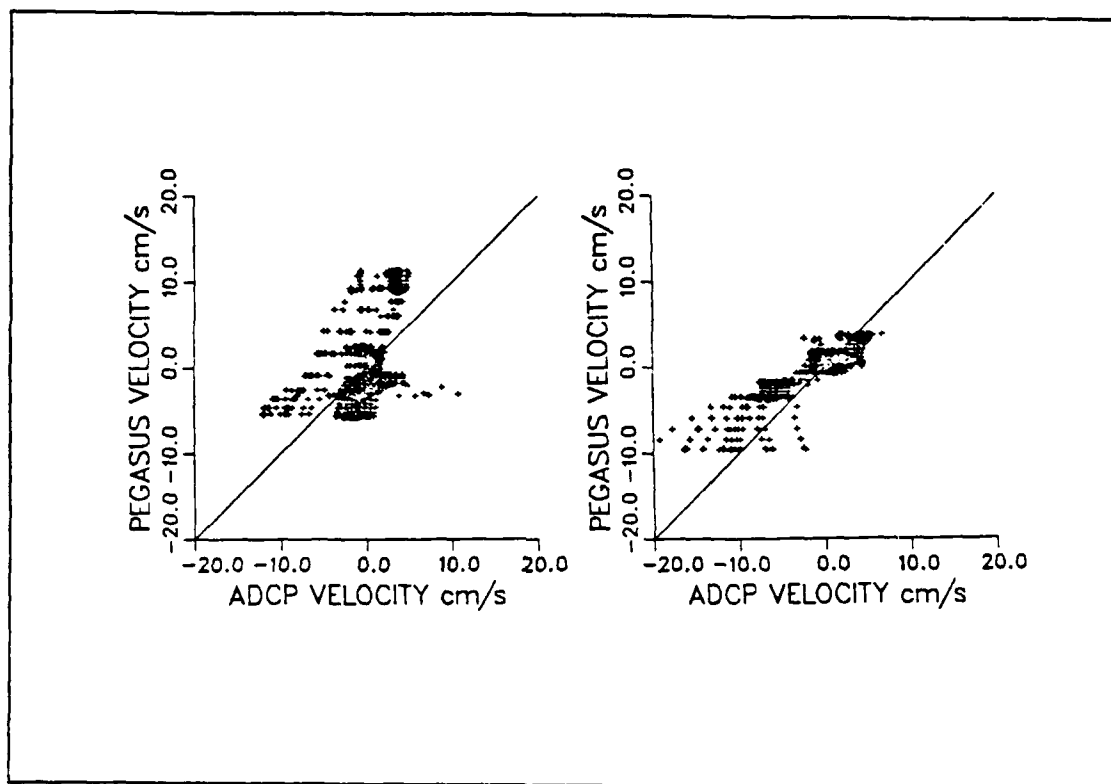
Figure 8.   PEGASUS vs ADCP velocity: U component is on the left. V is on
right.   The solid line is the ideal response.   Only velocities at depths
greater than 50 meters are shown.

inertial flow). If, for example, the velocities are measured in the inertial period at equal
times to either side of the point where the U component goes to zero, it would be ex-
pected that the U component would have a high correlation coefficient while the V
component would have a large negative correlation. If, on the other hand, the velocities
were measured at the same time separation as used above but the first profile was
measured when the U component was zero and the second was measured when the V
component was zero, the correlation would be expected to be zero for both U and V.
Thus, the correlation coefficients calculated between the upcast and downcast are very
difficult to interpret, except in the cases of shallow water where the downcast and cor-
responding upcast are very close together in the inertial period.

It should be noted that the velocity components used in this study
are total flow velocity components, including the mean flow and inertial flow. It would

be possible to average two profiles separated by one-half of an inertial period to define the mean flow and remove it, thus allowing comparison of the inertial flows and determining it's strength relative to the mean flow. However, that is not the purpose of this paper and is left to future efforts.

Inertial oscillations are not the only effects which could explain the differences seen between the PEGASUS upcast and downcast. Internal waves, changes in the mean flow regime, etc. could also be important. The change in depth offset, which was mentioned earlier, between PEGASUS upcast and downcast apparent in the visual profile comparisons could be explained in part by these as well. Differences between ADCP or PEGASUS profiles and spatially correlated geostrophic profiles could also be explained by the inclusion of internal waves.

The interpretation of correlation coefficients for ADCP profiles and the associated PEGASUS profiles should be much more straightforward, since the inertial oscillation does not enter in to the comparison of profiles measured at roughly the same time. Likewise, the passage of internal waves and large changes in the mean flow regime would not be expected on short time scales and should not be expected to complicate the interpretation.

The correlation coefficients calculated for the PEGASUS downcasts and associated ADCP profiles support the conclusions drawn from the earlier visual profile comparisons. Correlation coefficients for the earlier ADCP profiles and the PEGASUS downcast ranged from -.48 to .93 for the U component and from -.7 to .94 for the V component. The general trend in the correlation coefficients is for them to decrease in time. Table 3 on page 26 gives values of the U, V and horizontal speed correlation coefficients and time separation between the PEGASUS downcast profile and ADCP profile for cast 57. There were only two cases where early ADCP profiles showed negative correlation coefficients, these being cast 62 for the U component and cast 60 for the V component. These two casts were made at the same location.

A discussion of the PEGASUS upcast correlation with ADCP is not as meaningful as that for the downcast, the reason being that much less ADCP data was available for the period during the upcast due to the editing which had to be done to remove erroneous large velocities. However, an increase in correlation coefficient values as a function of time, similar to the decrease seen for the downcast, was not apparent. This could be because of the loss of ADCP data due to editing during the latter part of the upcast, degradation of the ADCP profiles due to ship maneuvers, changes in the PEGASUS sensitivity due to the dropping of the weights, or to differences in the flow

regime between the location of the ship and the PEGASUS. The first two possibilities seem the most likely, while the last two should not be very important. PEGASUS should not change drastically in sensitivity when weight is dropped as the amount of weight lost is only a small portion of the total instrument weight. The ship is maneuvering to be close by PEGASUS when it returns to the surface and spatial variations should not be large over these few tens or hundreds of meters.

(2) 'Problem' Profiles . The reason that the correlation coefficients for cast 62 U component are negative is uncertain. The coefficient for each ADCP U profile was negative for the PEGASUS downcast, but was positive, and strongly so, for the upcast. Also, the correlation coefficient for the downcast versus upcast U component was negative, but only very slightly so. If the PEGASUS had been deployed on the wrong side of the baseline, the downcast and upcast should be highly correlated while the ADCP profiles should be negatively correlated. Deploying PEGASUS on the wrong side of the baseline would not affect the V velocities. So it seems that this is not the explanation. If the locations of the transponders were reversed, both the downcast and upcast would be negatively correlated with the ADCP, so again this cannot be the explanation. Geostrophy cannot be used to determine the problem due to the orientation of the CTD line. It would be far more likely for inertial oscillations to strongly affect the U component due to it's lower mean flow and presumably larger inertial component. The cause of the problem remains a mystery and it is somewhat uncertain as to which velocities, if any, are in error. Investigation of this problem is currently underway.

A little more information is available for cast 60. The PEGASUS downcast and upcast V are highly correlated, as are both PEGASUS casts and the geostrophic velocity. The ADCP profiles are negatively correlated with the PEGASUS downcast and upcast as well as with the geostrophic velocity. This strongly points to the ADCP V velocities as being in error but short of an error in the initial data, no explanation of the reason can be made. Data processing is not the problem as all profiles utilized the same programs.

Actually, three other cases, casts 57, 58 and 59, also showed negative correlations for the U component both in the visual profile comparisons and when correlation coefficients were calculated. If PEGASUS had been deployed on the wrong side of the baseline between the two transponders, a reversal of the U component would be present in both the upcast and downcast, as was seen for these casts. Since large negative correlation was present in the comparisons of both the downcast and upcast when they were compared to the ADCP profiles as well as when checked for consistency with

25

Table 3. CORRELATION COEFFICIENTS, CAST 57.: Correlation coefficients for ADCP profiles and corresponding PEGASUS downcast profile. Note the low correlation coefficients for the time separation of 15 minutes. Visual correlation was also low.

Time Separation (min)	U	V	Horizontal Speed
0	.92	.93	.69
15	.01	.95	.15
30	.87	.94	.74
45	.65	.94	.68
60	.64	.93	.77
75	.42	.91	.82
90	.59	.91	.64
105	.56	.92	.65
120	.59	.92	.72
135	.51	.83	-.06
150	.56	.79	.60
165	.42	.60	.61

the surrounding flow, it was determined that the U component could be reversed to correct the error. PEGASUS profiles from previous cruises showed the same reversal at the same stations. Determination of the problem underlying this reversal will require special data collection on future cruises. However, for the present study, all discussion of the U component profiles applies to the profiles for these casts after they had been reversed.

(3) Vertical Shifts . In an attempt to correct the vertical offset between ADCP and PEGASUS profiles, the PEGASUS profiles were shifted upwards by as much as 44 meters, in 4 meter increments. No downward shifts were attempted since visual inspection showed that in all cases, the PEGASUS features were deeper than corresponding ADCP features. Also, the PEGASUS upcast and downcast were individually shifted upwards and the correlation coefficients for them were recalculated.

Results varied widely when comparing correlations for PEGASUS downcasts and the corresponding upcasts. In some cases, shifting the upcasts upwards increased the magnitude of the coefficients, while in others shifting the downcast upward increased them. Increases when either the upcast was shifted upwards were, in

26

almost all cases, accompanied by decreases as the downcast was shifted upwards, and vice versa. The vertical shift required to achieve the maximum magnitude of the correlation coefficients ranged from 0 to 40 meters, with the maximum shifts being required for the U components. The average shift required for the V components was approximately 20 meters. The V component would be expected to be more stable on the time scale of several hours being discussed here than would the U component, thus requiring less vertical shift.

The magnitudes of the correlation increases also varied greatly. PEGASUS cast 57 U correlation coefficients changed from -.00083 to -.70 for an upward shift of the upcast of 40 meters. Most increases were much smaller than this, some showing no increase at all. However, in most cases, significant increases were generally found when the profiles were shifted vertically.

The change in correlation as either the upcast or downcast is shifted vertically strongly supports the presence of internal waves. If the offset was due to a hysteresis problem, the shift would have to be consistently made in either the upcast or the downcast and would not change. Since the shift required is sometimes in the upcast and sometimes in the downcast, it is quite likely that the passage of internal waves is affecting the various casts differently. Also, the difference in the shift necessary for the U and V components may indicate that there is some inertial influence on the shift.

Correlation coefficients calculated between ADCP profiles and shifted PEGASUS profiles showed general improvement for both the PEGASUS downcast and upcast. The amount of shift necessary to give the highest correlation depended upon the cast, the individual ADCP profile being used, whether the correlation was for U or V velocity component, and whether the correlations were for upcast or downcast. The shifts giving the best correlations for the downcasts were typically four to 12 meters for the V velocities, with the U velocities needing a shift of about 20 to 28 meters. Shifts necessary for the upcasts were usually four to eight meters greater than for the downcast. There were profiles which required shifts outside these ranges but they were by far in the minority. When correlation was high for the unshifted profiles, less increase was seen as the profiles were shifted, with generally more increase as the profiles were shifted for cases where the correlation for unshifted profiles was poor.

Shifts on the order of four to 12 meters should be able to be made without hesitation as this is within the range of error for the PEGASUS pressure sensor [Ref. 7]. Shifts greater than this should be applied cautiously, and consistent offsets should be investigated further in order to solve the underlying problem.

27

No specific correlation coefficient values for the vertically shifted profiles are presented here since the number of influencing factors is so large and their interaction is so complex. The relative influence of temporal and spatial variations in the flow field due to mean flow changes, internal waves, and ship drift cannot be adequately separated with the present data set.

3. Comparison to Geostrophy

Visual comparison of geostrophic velocity profiles to ADCP and PEGASUS profiles (V component only) showed good agreement between the shapes of the curves with generally poor agreement between the magnitudes as expected since geostrophic velocity was calculated using an arbitrary LNM (Figure 9). In addition, the profiles had to be shifted vertically by as much as 40 meters for the shape of the curves to agree. This depth offset can be partially due to the same factors previously discussed for ADCP and PEGASUS with the additional inclusion of possible CTD depth error, presumed to be small. Also, due to the fact that geostrophic velocities are calculated from data taken at two stations widely separated both in space and time and assumes that the pressure gradient is linear between those two stations, a depth error could be introduced if, for example, there is a front between the two CTD stations. Depending upon the location of the ADCP or PEGASUS profile relative to the front and the CTD stations, the correlation between these profiles and geostrophy could vary from good to poor. It is not as questionable to arbitrarily shift geostrophic profiles vertically as it is to shift the PEGASUS and ADCP profiles, since the reason necessitating the shift is better understood.

In all cases, shifting the geostrophic profiles vertically increased the correlation with both ADCP and PEGASUS profiles. The amount of shift necessary to achieve the maximum correlation coefficient varied widely. It would seem logical that the amount of shift required would depend upon the particular features in the area as well as the time separation of the CTD casts compared to the ADCP or PEGASUS profiles. Since the CTD casts used to calculate geostrophic velocities are separated in time and thus no real time is associated with the resulting geostrophic profile, the geostrophic profiles must be correlated to ADCP and PEGASUS profiles based entirely upon location. The passage of internal waves could induce a vertical offset in either or both of the CTD casts resulting in an uncertain amount of offset in the geostrophic velocities. Location of a front between adjacent CTD stations could also result in offset geostrophic velocities. Further complication is introduced when the geostrophic profiles are interpolated to the same locations as the ADCP and PEGASUS profiles.
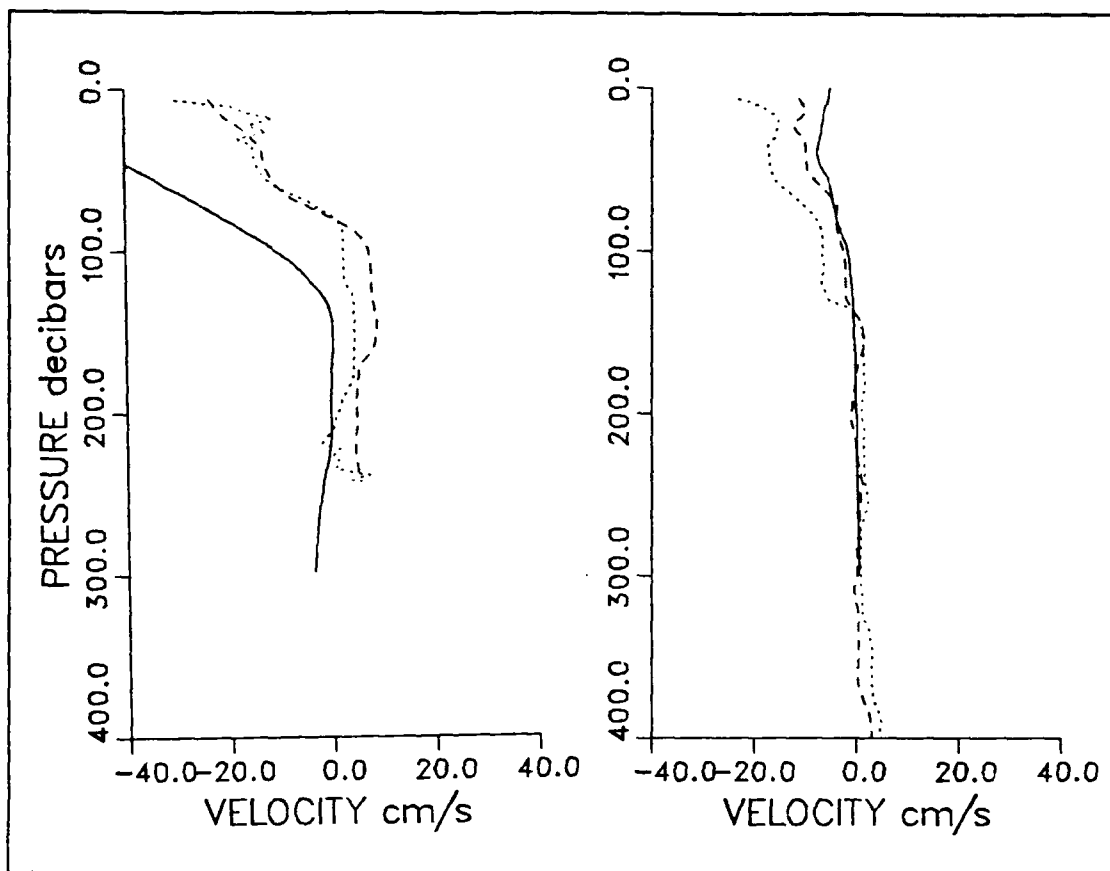
28

Figure 9. Geostrophic, ADCP, and PEGASUS V Velocity: Cast 53 is on the left, cast 57 on the right. The solid lines are geostrophic velocity, dashed is ADCP and dotted is PEGASUS.

Correction of geostrophic profiles using a level-of-known-motion derived from the ADCP profiles will be covered in the following section.

B. VELOCITY SECTIONS

Several types of comparisons were made between contours of ADCP, PEGASUS and geostrophic velocity components. The goal of this contour analysis was to describe the relation of features, both in the horizontal and vertical, between the various profiles.

Somewhat arbitrarily, it was decided to use the second ADCP profile for each cast for the contours. This was done because the first ADCP profile may still contain some data from while the ship was in transit, even though attempts were made to ensure that this was not the case. The contours presented are felt to include the best data available.

29

PEGASUS downcasts are used as they provided the highest correlation to geostrophy and ADCP profiles. Other contours were examined with similar results to those presented here.

Geostrophic contours were drawn using profiles which had been corrected using and ADCP level-of-known-motion (LKM). It was found that the assumed LKM had very little effect on the location of features. Values of 23, 43, 63, 83, 103, and 123 meters for the LKM were used with the magnitude of the corrected geostrophic velocities being virtually identical for the first four values. For LKM values of 103 and 123 meters, the magnitude did begin to change appreciably which could be due to the ADCP decreasing resolution with increasing depth. The profiles could under-represent features at deeper levels to such an extent that the LKM correction to geostrophic velocity is incorrect. Based upon this argument, the geostrophic profiles using the 63 meter LKM was used, which placed the LKM well away from the highly variable surface zone. This also avoids problems involving the use of the data near the surface which is unfiltered. An LKM of 83 meters could have been used with similar results.

Due to the vertical offset in geostrophic velocity compared to the ADCP profiles, it is very unsure that the geostrophic velocity was corrected using the ADCP velocity from the same level in the ocean. Due to the similarity of the features seen on the contours, it is felt that neglecting the vertical offset of the geostrophic velocity profiles is justified. When comparing the contours, it should be kept in mind that the features may be offset by a fairly large amount vertically, perhaps 60 meters or more when all offsets are included. Horizontally, the features should match well due to the scale at which the contours are plotted.

In the cases in this study, there is little vertical shear in the range of depths considered for use as an LKM. In cases where there is appreciable vertical shear, it would be necessary to use a vertically averaged velocity at the LKM. No differences were seen when this · s done for these cases, and so to simplify the data processing, the velocity at a single epth was used.

The analysis of the PEGASUS, ADCP and geostrophic velocity contours showed excellent correlation of features, both in space and in magnitude. Figure 10, Figure 11, and Figure 12 show the resulting contours.

Contours of geostrophic velocity and PEGASUS V velocity were plotted from the surface to the bottom as shown in Figure 13 As can be seen, the major features of these contours are similar.
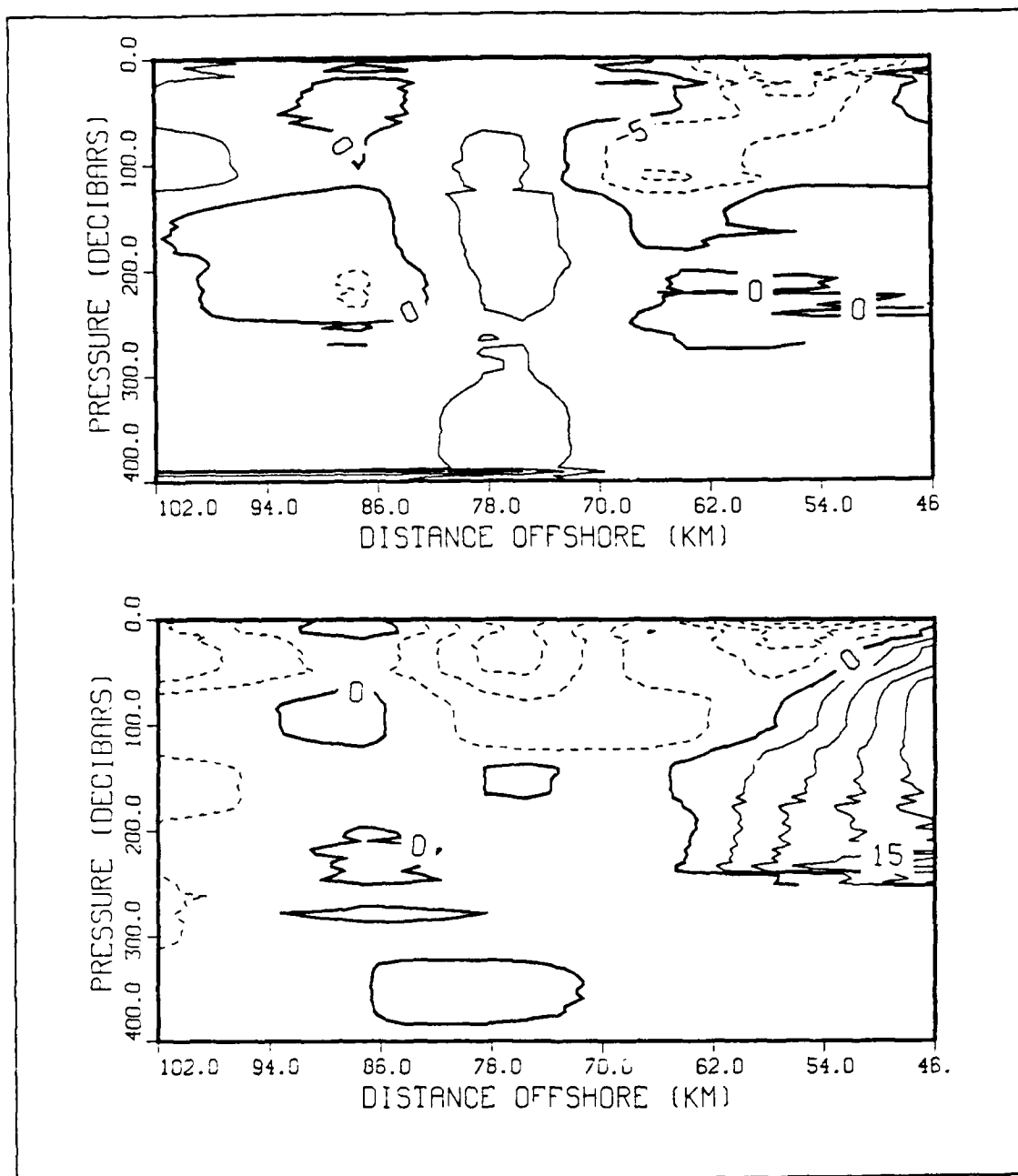
Figure 10. ADCP velocity component contours: The U velocity component is on top, V is on the bottom. Velocities are in cm/s with contours being at 5 cm/s increments. Eastward/northward flow contours are solid.

31

Figure 11. **PEGASUS velocity component contours:** The U velocity component is on top, V is on the bottom. Velocities are in cm/s with contours being at 5 cm/s increments. Eastward northward flow contours are solid.
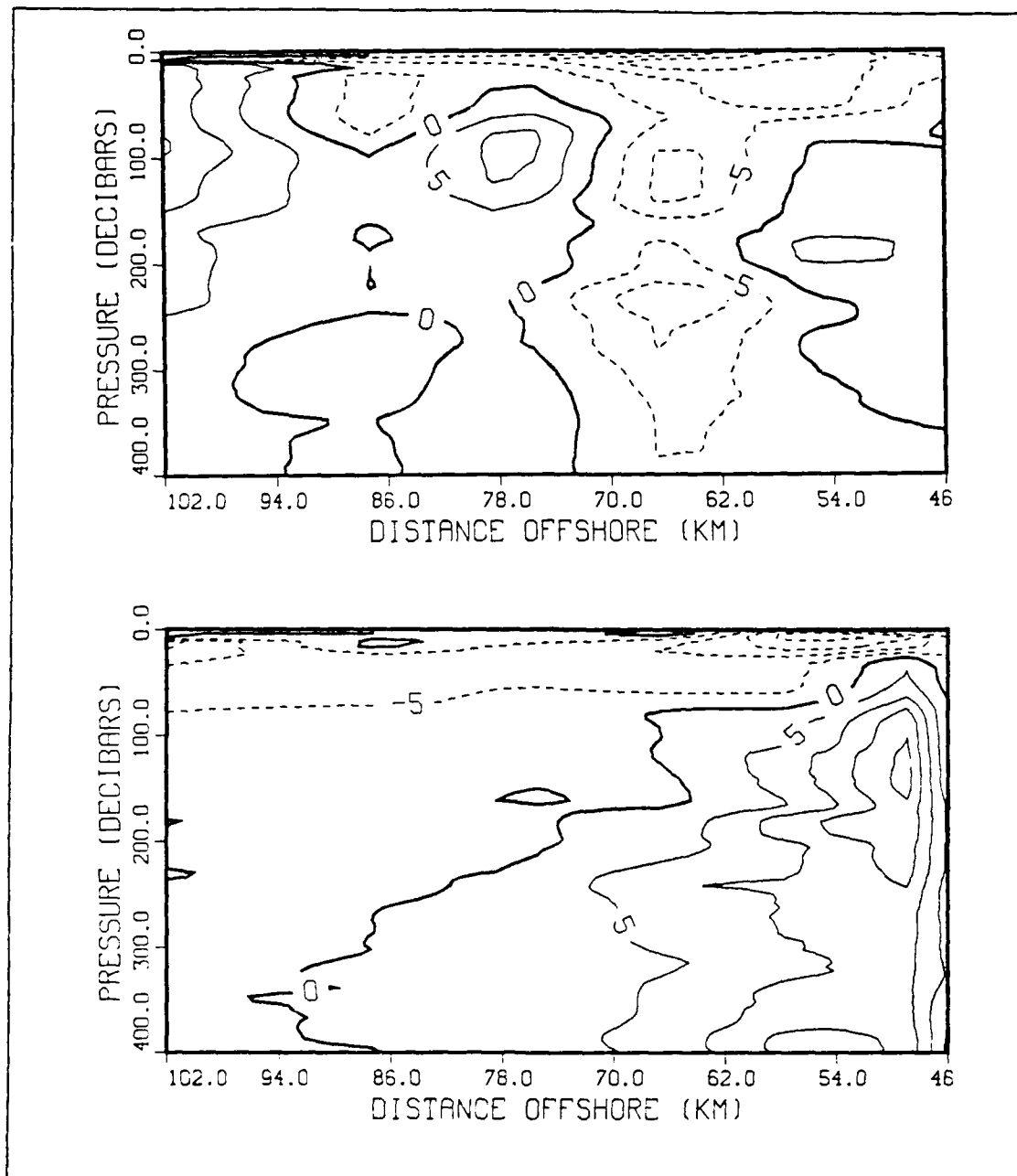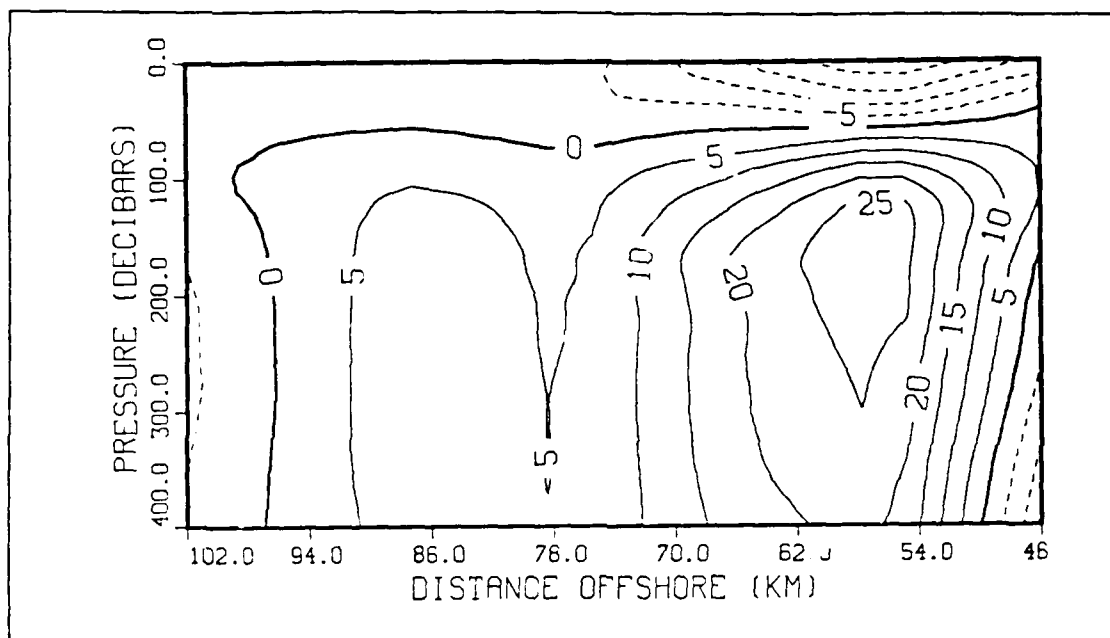
32

Figure 12. Geostrophic velocity contours: V component only. Velocities are in cm s with contours at 5 cm/s increments. Northward flow contours are solid. Velocities were calculated using an ADCP level-of-known-motion of 63 meters.

Comparison of the surface-to-bottom contours of geostrophic and PEGASUS V velocity also show very good similarity. One notable deviation from geostrophy is near the right edge of the section from 50 to 1000 meters depth where PEGASUS and geostrophy show differences in flow direction. Also, the southward flow at the left of the section at depths below 1000 extends much further inshore on the PEGASUS contours than is shown geostrophically. Overall, the agreement with geostrophy for both the ADCP and PEGASUS profiles is excellent.

C. VERTICAL VELOCITY

Although vertical velocity measurements are provided by the ADCP, the noise inherent in the ADCP profiles generally obscures the small vertical velocities typically present in the ocean. The contour of vertical velocity shown in Figure 14 does show one very interesting feature, this being the downward motion of greater than two cm s located near 53 km offshore. This is much larger than the velocities elsewhere in the section and is much higher than would be expected. Sections plotted using other ADCP
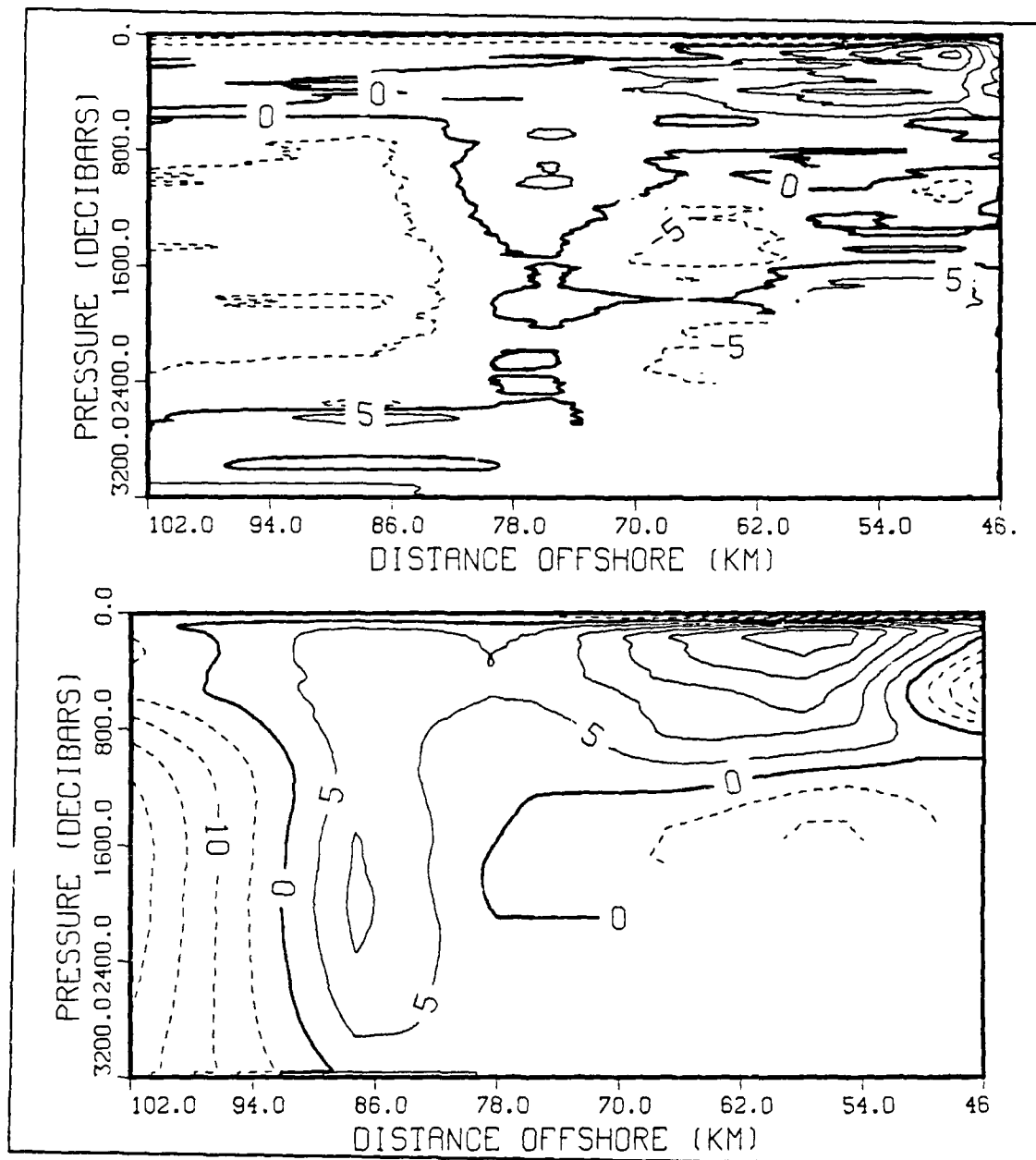
33

Figure 13. **PEGASUS and Geostrophic velocity contours:** The PEGASUS contour is on top, geostrophic is on bottom. Velocities are in cm/s with contours being at 5 cm/s increments. Northward flow contours are solid. Geostrophic velocities were calculated using an ADCP level-of-known-motion of 63 meters.

profiles sometimes showed similar vertical velocities, while in other cases, the large vertical velocities were absent. These unusually large vertical velocities could be due to noise or the normal daily vertical excursion of biologics. However, due to the fact that they are not present consistently in all profiles in a particular location, they are probably not indications of actual vertical motion of the water column.

D. COMPARISONS TO HISTORY

The flow fields defined by the PEGASUS, ADCP and geostrophic velocity contours in this study compare well with historical flow fields. Chelton [Ref. 14] presents seasonal geostrophic velocity contours based on 23 years of data collected in the same area as this study. Taking into account that the section line used in Chelton's study was rotated about 30° counterclockwise from the line used in this study, the contours for September and October (Figure 15), based on a 500 dbar LNM, agree very well with those presented here, both in location and strength of the features.

Similarly, the contours presented by Breaker and Mooers [Ref. 15] taken along the same transect used in this study show excellent correlation with the contours presented here (see Figure 15), as do those presented by Lynn and Simpson [Ref. 16]. Breaker and Mooers used a LNM of 300 meters for their geostrophic velocities while Lynn and Simpson used 500 meters.

E. FLOW FIELD SUMMARY

Based on Figures 10 through 13, a description of the flow field can be made. Southward jets near the surface are indicated by both ADCP near 50, 75 and 100 km offshore extending to 50 to 100 meters depth with speeds ranging as high as 20 cm/s. The jets at 75 and 100 km are not supported by geostrophy as is the jet at 50 km. PEGASUS shows southward flow at the surface from 46 to 85 km offshore.

A strong northerly undercurrent is located near 60 km, extending from 50 m depth to the bottom. This current is highly geostrophic, but the southward geostrophic flow near 46 km offshore at depths greater than 150 meters is not indicated by either ADCP or PEGASUS. The ADCP data in that area is restricted to near the surface. The ADCP velocities are generally southerly offshore of 90 km, with the PEGASUS velocities being in the same direction but much weaker.

The strong southerly flow indicated by PEGASUS extending from about 85 km to 102 km offshore and 1000 to 3500 meters depth is fairly well supported by geostrophy. The deep northerly flow (to 3500 meters) indicated by PEGASUS at 75 km is nearer shore than the corresponding geostrophic flow. These differences are quite likely due to
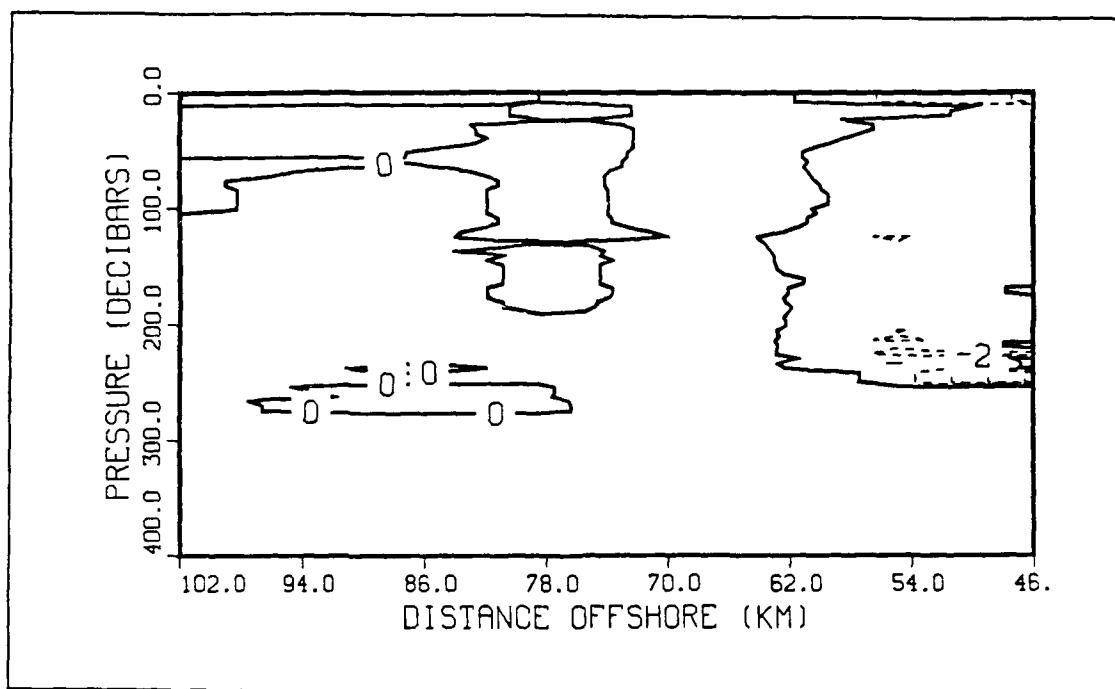
Figure 14. **Contour of ADCP Vertical Velocity:** Solid lines are upward motion. Contour interval is 2 cm s.

the times and locations at which the PEGASUS and CTD casts were made relative to each other.

Near surface offshore flow is indicated by both ADCP and PEGASUS extending from 46 to 80 km offshore. Ekman transport would support this in light of the proximity to the coast and the strong southerly flow in the same area. Offshore flow is also indicated near 65 km offshore and extending to at least 200 meters, and substantially deeper on the PEGASUS contours. A zone of strong onshore flow is located near 78 km, extending to depths of greater than 300 meters, with speeds of up to 10 cm/s.
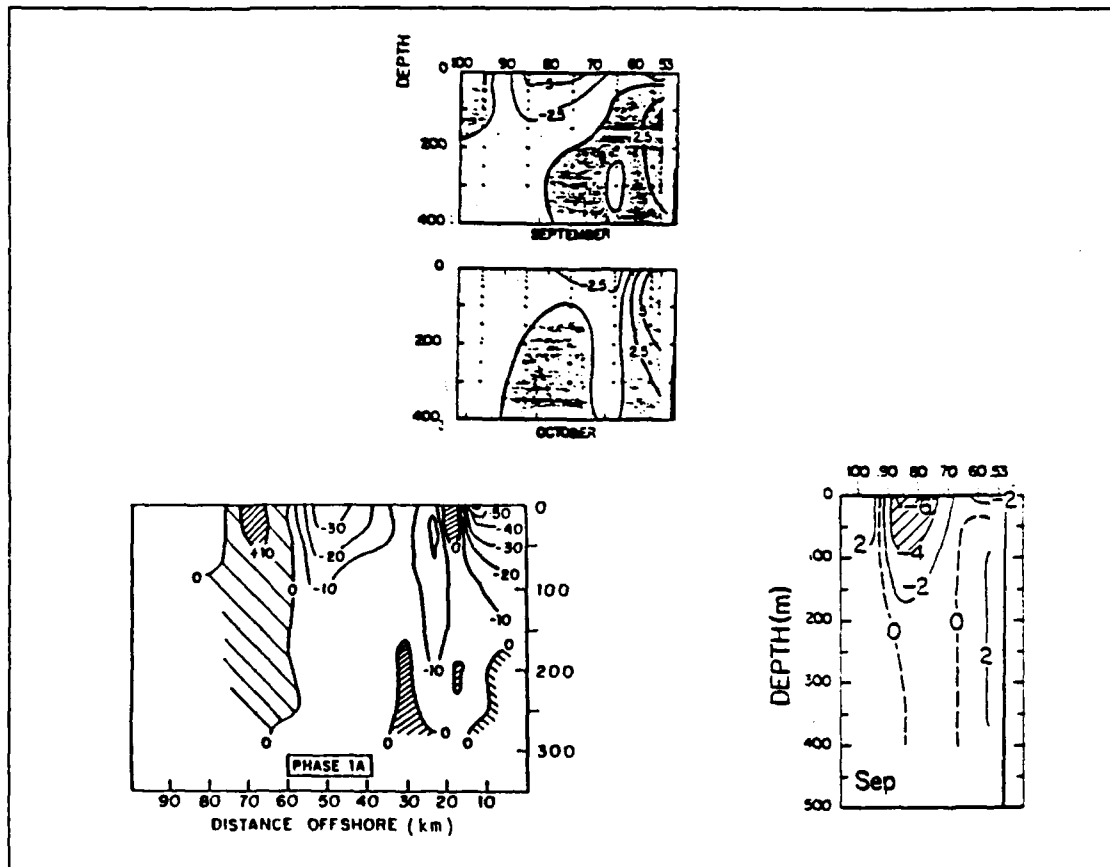
Figure 15. **Geostrophic Velocity Contours:** The upper two figures show geostrophic velocity during November and December as calculated from 23 year of CalCOFI data. (from Chelton [Ref. 14] The lower left figure is from Breaker and Mooers [Ref. 15], the lower right is from Lynn and Simpson [Ref. 16]. Data for these contours is from the same area as this study.

37

V. CONCLUSIONS

A. DATA PROCESSING

The massive amount of data which the ADCP can provide requires that the collection and processing procedures be carefully designed. Collecting the data as three to five minute averages is adequate, and only under the very special circumstances of constant ship speed with small or slow course changes should the averages be longer. Even under those circumstances, the advantages are minimal. Considering the normal operations of an oceanographic cruise where numerous large course and speed changes are the norm, the shorter averages should definitely be used.

Vertical filtering of the ADCP data is necessary to remove noise. For the four meter vertical resolution of this study, Hanning window halfwidths of two to five depth bins (eight to 20 meters) provided the best reduction of variance without excessive loss of signal, although seven bins (28 meters) was used to match the filter width necessary for PEGASUS data. It is quite possible that this would not be the proper filter to use for data collected at other depth resolutions or in other flow regimes. Also, it is quite likely that the use of ADCP data obtained from a ship which was not drifting, as this was, could require a different type of filter.

Although data is collected as short time averages, further averaging of the data is necessary during post-processing for reasonable absolute velocities to be provided. Averages of 15 minutes provide adequate absolute velocities while retaining the actual short-term variability occurring in the ocean. Again, it is quite likely that the use of ADCP data recorded by a ship which was not drifting would require the use of a different length of time average.

PEGASUS velocity profiles must likewise be vertically filtered. Variance analysis showed no major decrease as the filter was applied, but visual inspections of filtered versus unfiltered profiles showed that a 30 meter filter was adequate. As for the ADCP data, this may change for other flow regimes.

B. COMPARISONS

ADCP profiles showed excellent agreement in velocity shear between successive unaveraged profiles, as did the 15 minute average profiles. Absolute velocity comparisons of the unaveraged profiles were generally poor, with those of the 15 minute averages being much better.

Comparisons of PEGASUS downcast velocities to those of the upcast showed good to poor agreement, depending upon the depth of water, and thus time between casts. Agreement also depended upon the strength of features in the vicinity of the cast, with the casts having strong features showing better agreement than for the casts with weaker features. It is necessary to undersatnd more fully the inertial and internal wave effects during the period between downcast and upcast.

The comparison of vertical velocity profiles as measured by PEGASUS and ADCP show good agreement for the vertical location of features, but they often vary widely in magnitude. The profiles are in best agreement when they are measured at similar times, with the agreement decreasing as time separation increases. Due to ship drift, a time separation also implies a spatial drift, complicating the comparisons. Agreement was better in the middle depths than near the surface or the bottom of the ADCP profile due primarily to reverberation near the surface and the decrease in ADCP horizontal resolution with depth. The V (alongshore) velocities agreed better than did the U (crossshore) velocities due to their larger magnitude and, therefore, smaller inertial components.

Currents were found to be highly geostrophic. It was found that the actual choice of the ADCP level-of-known-motion was fairly unimportant as long as the depth chosen was not too near the surface, where there are large variations in currents and deviations from geostrophy, nor too deep in the water column, where the ADCP horizontal resolution has decreased excessively. Depth choices of 60 to 80 meters show the best results. Contours of ADCP, PEGASUS and geostrophic V velocity show similar horizontal and vertical feature locations as well as similar magnitudes. The vertical feature locations sometimes differ by several tens of meters due to the time and spatial variations between times of CTD, PEGASUS and ADCP data collection. The largest vertical differences in features are in the geostrophic velocities.

One PEGASUS cast exhibited reversal of one velocity component between the upcast and downcast. No reason for this reversal can be found, and it does not appear to be real. Several casts also showed a reversal in one flow component between the PEGASUS and ADCP profiles. Several reasons for this are suspected but no definitive answer is yet available, but analysis of the surrounding flow can provide guidance on the possible correction of the data, provided that the surrounding flow is sufficiently well defined by other instruments.

C. RECOMMENDATIONS

An objective method is needed for separating ADCP data collected while the ship is on station vice that while the ship is underway, thereby eliminating the complications encountered when filtering ship velocity across large changes in speed and direction. A possible aid would be to record ship position data more often so that ship movements could be more accurately determined, thus providing a better gauge of when the ship is actually changing speed and direction. This is very difficult with ship positions recorded at 3 minute intervals, as in this study, and becomes increasingly difficult with increasing recording intervals.

The apparent velocity component reversals noted between the PEGASUS downcasts and upcasts should be studied and a determination made as to whether it is real or an error in the data collection and processing. The same holds for the reversals noted between PEGASUS and ADCP velocities.

The change in sensitivity of the PEGASUS, if any, when weights are released at the bottom of the downcast is not known. This, as well as a pressure measurement error, could be responsible for the vertical offset noticed between the downcast and upcast and should be evaluated.

A determination should be made whether or not the RDI ADCP has a temperature measurement lag time similar to that associated with the Ametek-Straza instruments. If so, it should be corrected or an alternate temperature sensor should be employed.

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